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Evaluation of human error probability of disc brake unit assembly and wheel set maintenance of Railway Bogie

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Abstract

The railway sector is key to the continuous expansion of industrialized nations, but the sector's working conditions and human performance requirements are qualitatively different from other industries. Human error in railway maintenance is a subject which warrants serious attention so as to achieve and sustain a competitive advantage. This paper investigates the probability of human error during the maintenance process of disc brake assembly unit and wheel set of railway bogie under various error producing conditions in railway maintenance workshop in Luleå, Sweden. The objective is to evaluate human error probability so as to take measures to reduce the likelihood of errors occurring within a system and, thus, to improve the overall levels of safety. For this paper, a case study that explores the causes of maintenance error during disassembly, inspection, maintenance, assembly and installation was derived from brain storming sessions among subject matter experts (SMEs), i.e technicians, supervisors and academic experts. In our case study, the Human Error Assessment and Reduction Technique (HEART) was implemented to evaluate the probability of human error occurring throughout the completion of maintenance task. HEART is based upon the principle that every time a task is performed on the maintenance of a disc brake assembly unit and wheel set, there is a likelihood of failure and the probability of this is affected by one or more error producing condition, for instance, shortage of time, over-riding information, inexperience etc. This paper presents the need for interventions in the human factor elements of maintenance tasks performed on railway bogie. A number of factors directly or indirectly result in a decline in human performance, leading to errors in maintenance tasks. The probability of a technician committing an error during maintenance of the disc brake assembly unit and wheel set is found to be 0.20 and 0.039 respectively. It has been observed that error producing conditions such as time pressure, ability to detect and perceive problems, the existence of over-riding information, the need to make absolute decisions, and a mismatch between the operator and the designer's model are major contributors to human error.

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1. Introduction

Technicians in railway maintenance tasks are confronted with a set of error producing conditions within strenuous railway maintenance systems, including time pressure, negligible feedback, confined work spaces, awkward body positions (bent and/or twisted backs, both arms above the shoulder etc.), poor written procedures, lack of access to the equipment etc. These conditions, in combination with basic human tendencies, result in various forms of errors. This calls for more research if the railway sector is to thrive and grow. Human error contributes to the majority of incidents within complex systems, including the railway system. Over the years, a large number of railway accidents [1] resulting in many injuries and fatalities, and a high financial cost have occurred due to human factors-related problems in the design and operation of railway systems around the world [2-4]. To cite only a few examples, from 1970 to 1998, 62% of the 13 railway accidents in Norway were due to human error [5]. While during the same period, on four British railway lines, 141 accidents were caused by human error [5, 6], several persons killed at Clapham Junction. As reported by the Rail Accident Investigation Branch [7], a train travelling from London to Glasgow derailed when a fault in the stretcher bar of the points caused the left and right switch rails to become disconnected. Although it is nearly impossible to eradicate human error, it can be minimized through good maintenance management and an understanding of the issues that affect errors [8]. Human error, in general, can be defined as the failure to perform a specific task that could lead to disruption of scheduled operation or result in damage to property and equipment [9]. Dhillon [10] claimed that maintenance error is linked to incorrect repair; further, the occurrence of maintenance errors rises with increased maintenance frequency. Maintenance errors risk lives and resources and have an adverse effect on business, and are especially problematic in hazardous technologies [11]. Human errors in railway maintenance include among others disassembly errors, inspection errors, maintenance errors, assembly errors and installation errors. The reasons for these include lack of training, interrupted flow of information, unclear written maintenance manuals, inadequate lighting, poor equipment design, high noise levels, inadequate work layout, improper tools etc. Since error is endemic to mankind, understanding the root causes of errors and attempting to minimise them are necessary. Good railway management will keep track of performance, especially failures, to ensure problems are eliminated before they become endemic. On the rolling stock, the maintenance of brakes and wheels is crucial. These important security systems must meet strict security rules, in terms of stopping distance associated with a maximum average deceleration, in all sorts of environmental conditions. For this paper, a case study that explores the causes of maintenance error was derived from brain storming sessions among subject matter experts (SMEs), i.e technicians, supervisors and academic experts. The objective of those discussion was to identify potential factors causing overall effect in order to reveal key relationships among various factors, and the possible causes offer supplementary vision into process behavior. The railway maintenance workshop of our case study, uses R1 (smaller) and R4 (detailed) types of maintenance audit programs for Railway bogie. R1 is a smaller maintenance audit and is carried out after a maximum 1200000 km, whereas R4 is more detailed and done after 3600000 km. The R1 maintenance audits for Railway bogie corresponds to detection, monitoring and repair of disc brake unit assembly, wheel sets and bogie frames. This paper investigates human error probability (HEP) in maintenance of railway bogies based on the workshop held in Luleå, Sweden. It considers human error probability (HEP) during the maintenance tasks for disc brake assembly units and wheel sets in various error producing conditions, as these are the most frequent identified cases of maintenance errors.

1.1. Disc brake assembly unit

The disc brake assembly unit on the bogie has four brake packages. Each brake package includes a braking motion and a brake unit (Fig. 1). The brake unit consists of a brake actuator integrated with a brake controller. For a pair of wheels, two brake packages are mounted on special cross beams in the bogie. On the cross member, mounts keep the plates and brake pads in the correct position against the brake disc. The wheel set has two brake discs; each is associated with a specific lever in the brake unit. The brake force from the brake unit is amplified and transferred to the brake pads and brake disc. Careful and regular maintenance is required to ensure even the distribution of forces to all wheels. Badly set up rigging will cause wheel flats or lead to inadequate brake force. If brakes on the

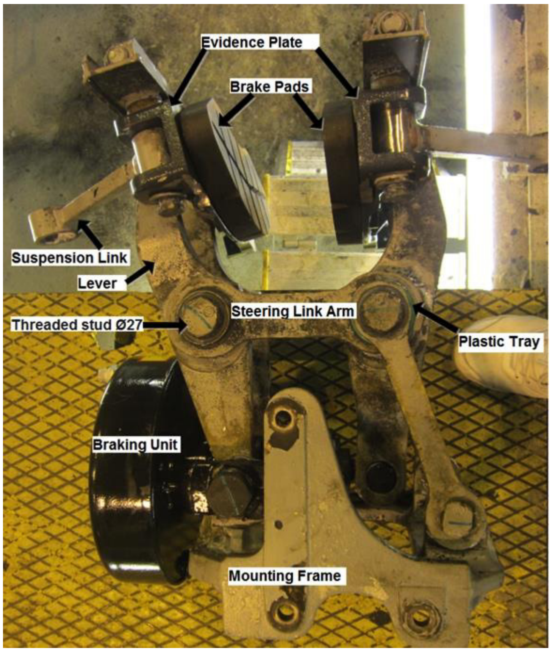

Fig. 1. Disc brake assembly unit of Railway Bogie.

wheels of one axle are not equal, the wheel on which braking pressures are higher has the tendency to roll less, causing an angular run during braking. There are other problems as well: unequal wear on brake shoes causes unequal braking pressure on the wheels of an axle; wheels are often damaged by skidding during braking; an eccentric wheel can cause extreme loads on the wheel, axle, bearing and suspension, leading to failures. Brain-storming sessions in railway maintenance workshops have also revealed that insufficiently executed maintenance tasks on the disc brake assembly unit, such as improper lubrication of the brake disc, undersize fitting of the brake block, improper fitting of tapping screws and cylindrical bolts can cause serious errors. Moreover, incorrect measurement of brake movement results in a delay in brake lever movement, thereby reducing brake performance. This affects the distribution of braking forces from a brake cylinder to the wheels on the vehicle.

1.2. Wheel-set maintenance

A wheel-set is the wheel-axle assembly of a railroad car. The frame assembly beneath each end of a locomotive that holds the wheel-set is called the bogie. During maintenance, wheels must be checked for deviations from a standard profile. To this end, the technicians in the maintenance workshop perform visual inspections (maintenance type R1) of the wheel set, axle mounted brake disc and bearing box [Fig. 2 (a)]. Visual inspection of an axle mounted brake disc and wheels can identify cracks [Fig. 2(b)] and surface imperfections. If the brake disc and wheel develop signs of wear or cracking, they are directly sent to the workshop for necessary action. The bearing box is revolved manually to listen for any abnormality in sounds from the inside of the box. These manual tasks enhance the probability of human error; technicians must identify wheel cracks and wear visually, without tools or equipment to assist them, and also listen to the noise in bearing box. The latter task is especially problematic because of noise in the workshop. Wheel profile measurement, such as fin height, flange thickness, diameter of running circle, limit to turning, and Qr (flange slope), is done manually [Fig. 2(c)] as well, escalating the probability of human error and possibly resulting in wheel-set misalignment and increased fuel consumption. In addition, poor wheel profile can cause metal fatigue, wear, corrugations, and other defects that require maintenance and untimely replacement. In short, a key part of reducing railroad costs (i.e., fuel costs), improving safety (i.e., decreased derailment risk), extending life, and enhancing stability is possible by improving the maintenance of wheels and the disc brake unit.

Fig. 2. (a) Axle mounted brake disc ; (b) Cracks on brake disc; (c) Manual wheel profile measurement.

2. Methodology

There are several methods to analyse and predict the probability of human error. Williams first suggested that realistic system reliability analysis must embrace the human aspect [12, 13]. The participants in our study were certified technicians, aged 52-55 years, with a height of 178-190 cm and a weight of 75-85 kg; all had 25-30 years of work experience. None had a history of chronic or acute illness, hypertension or any other major health issues, and none took any prescribed medication. The workers were monitored while doing maintenance and questioned during and after the task. In our case study, the Human Error Assessment and Reduction Technique (HEART) has been implemented to evaluate the probability of a human error occurring throughout the completion of a specific task. HEART is highly flexible and applicable in a wide range of areas which makes it a popular choice [14]. We selected HEART because it is a task-based analysis [15] not a decompositional approach focusing on types of error. Moreover, HEART incorporates the most widely used estimates of error rates of generic tasks. There are 9 Generic Task Types (GTTs) described in HEART, each with an associated nominal human error probability (HEP), and 38 Error Producing Conditions (EPCs) that may affect task reliability, each with a maximum amount by which the nominal HEP can be multiplied. In our research we selected Generic Task F (F= 0.003, restore or shift a system to original or new state following procedures, with some checking). The brainstorming session with technicians, supervisors and academic experts allowed us to identify human activities leading to a potential system failure. We then built a fault tree to determine the interactions leading to the failure. The tasks related to the maintenance of the wheel set and disc brake unit were identified and examined in detail and the information reviewed from the perspective of risk analysis of the system. These tasks were then grouped into disassembly tasks, inspection tasks, maintenance tasks, assembly tasks and installation and testing tasks. Each was further divided into errors in subtasks, such as D1, D2, D3, D4 (for disassembly), M1, M2, M3, M4, M5 (for inspection and so on; see Table 1). Based on the HEART table [16] nominal human reliability values were assigned to each task. Once a task description was constructed, we derived nominal human error probabilities for task error [16]. Human error probability was evaluated by applying error producing conditions [16] and engineer's proportion of affect (EPOA). EPOA ranging from 0-1 was assigned to each task by an industry expert. In certain cases, more than one error producing item was selected and applied in the formula to calculate final human error probability:

$$(HEP) = \text{GTT x A1x A2x} \ldots \text{ An}$$

Where GTT is human error probability associated with each generic task.

$$\text{A1} = \text{Assessed effect} = ((\text{Total Heart effect} - 1)\text{x EPOA}) + 1$$

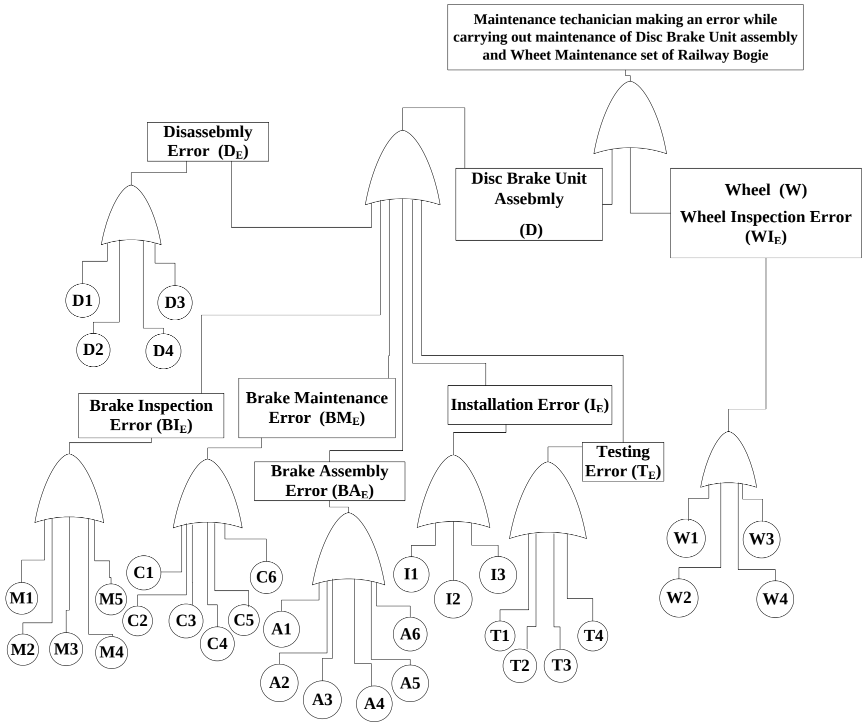

Fig. 3. Fault tree for technician making error during maintenance of Railway Bogie.

2.1. Fault tree analysis

Fault tree analysis (FTA) was developed in the early 1960s at the Bell Telephone Laboratories to perform safety analysis [17]. It is used broadly to perform reliability analysis of engineering systems and it is a logical representation of the relationship of fault events that may cause an adverse event, called the top event, to occur. The events that result in the occurrence of a top event are connected and generated by logic gates, expressed by ANDs and ORs. The OR gates provides a true output (i.e., fault) when one or more of its inputs are True (fault). In this study, fault tree analysis (FTA) was used to perform human error analysis in the railway maintenance of bogie. After analyzing maintenance tasks, the top fault event (technician making an error while doing maintenance of disc brake unit assembly and wheel set) and possible causes or basic fault events (brake disassembly error, brake inspection error, brake maintenance error, brake installation and testing error, wheel inspection error) that cause the top event to occur were identified using OR gate. A fault tree was then developed down to the lowest level. The occurrence probability of the technician making an error (top event) was calculated using the probabilities of occurrence of basic fault events (disassembly error, brake inspection error, brake maintenance error etc; see fig. 3). We are taking the assumption that input events occur independently and the probability of occurrence of the OR gate output fault event [18]. where P(y0) is the probability of occurrence of the OR gate output fault event, y0, k is the number of OR gate input fault events, and P(yi) is the occurrence probability of OR gate input fault event yi; for i = 1, 2, 3, …, k.

$$P(y_0) = 1 - \prod_{i=1}^{k} \{1 - P(y_i)\}$$

Table 1. Human error probability (HEP) of each sub-task associated with the maintenance of disc brake assembly unit and wheel set.

	Maintenance of Disc Brake	Nominal Human Reliability			
	Errors in Disassembly Task	Eror producing Conditions (HEART Effect)	EPOA (0-1)	Assessed Effect	HEP
D1	Technician failed to successfully take out the brake unit from lever arms (causing sudden release of brake unit)	• Shortage of time available (X11)	3	((11-1)x0.3)+1=4	.012
D2	Damage to brake pads while removing them from the evidence supports.	• Over-riding information (X9)	4	((9-1)x0.2)+1=2.6	.007
..	………..	…………	…	………	……
	Errors in Measurement and Inspection task				
M1	Technician failed to check the parts for cracks for any deformation and other external damage on link, arm and mounting frame (damage more than 3 mm in depth is assessed as a crack)	• Ability to detect and perceive (X10)	4	((10-1)x0.4)+1=4.6	.01
M2	Technician failed to check correct dimensions of lever and steering link arm	• Ability to detect and perceive (X10)	3	((10-1)x0.3)+1=3.7	.01
..	…………	…………	…	………	……
	Maintenance of Wheel				
	Errors in Inspection and Monitoring task				
W1	Technician missed identification of all cracks on the surface of the wheel	• Ability to detect and perceive (X10)	5	((10-1)x0.5)+1=5.5	.016
W2	Technician unable to predict the level of noise coming from Lagerbox.	• Need for absolute judgment (X1.6) • Ability to detect and perceive (X10)	4 4	((1.6-1)x0.4)+1=1.2 ((10-1)x0.4)+1=4.6	.016
..	…………	…………	…	………	……

3. Results and discussion

The Human Error Probability (HEP) of each sub-task associated with the maintenance (Type R1) of disc brake assembly unit and wheel sets was evaluated using the HEART (Table 1). The principle of this case study was that every time a task is performed during maintenance, there is a likelihood of failure; this facilitated our evaluation of the probability of human error associated with each task and allowed deeper understanding of the impact of each individual task.

The probability of the occurrence of causes (fault events) was evaluated using the fault tree method. The OR gate provides a true output (i.e., fault) when one or more of its inputs are True (fault). The probability of occurrence of event disassembly error ((BIE), inspection error (BIE), maintenance/repair error (BME), assembly error (BAE), inspection error (IE), testing error (TE) was calculated using the formulas (1-6):

$$P(BI_E) = 1 - [1 - P(M1)][1 - P(M2)][1 - P(M3)][1 - P(M4)] \quad (1)$$

$$P(BM_E) = 1 - [1 - P(C1)][1 - P(C2)][1 - P(C3)][1 - P(C4)][1 - P(C5)] \quad (2)$$

$$P(BA_E) = 1 - [1 - P(A1)][1 - P(A2)][1 - P(A3)][1 - P(A4)][1 - P(A5)][1 - P(A6)] \quad (3)$$

$$P(I_E) = 1 - [1 - P(I1)][1 - P(I2)][1 - P(I3)] \quad (4)$$

$$P(T_E) = 1 - [1 - P(T1)][1 - P(T2)][1 - P(T3)][1 - P(T4)] \quad (5)$$

$$P(D_E) = 1 - [1 - P(D1)]\,[1 - P(D2)]\,[1 - P(D3)]\,[1 - P(D4)] \tag{6}$$

The maintenance of the disc brake unit includes disassembly, measurement and inspection, corrective maintenance, assembly, installation and testing; the probability of human error is each task was found to be 0.04, 0.04, 0.05, 0.05, 0.02 and 0.03 respectively. The probability of event D occurring (the technician committing an error while performing maintenance on the brake disc unit) was determined to be 0.2093 using the following formula (7):

$$\begin{aligned} P(D) &= 1 - [1 - P(BI_E)]\,[1 - P(BM_E)]\,[1 - P(BA_E)]\,[1 - P(I_E)]\,[1 - P(T_E)]\,[1 - P(D_E)] \\ P(D) &= 0.2093 \end{aligned} \tag{7}$$

Likewise, the probability of event W (wheel maintenance error) occurring was found using equation (8):

$$P(W) = 1 - [1 - P(W1)]\,[1 - P(W2)]\,[1 - P(W3)],[1 - P(W4)] \tag{8}$$

The overall probability of event M (technician making an error while doing maintenance) occurring was evaluated as shown below:

$$\begin{aligned} P(M) &= 1 - [1 - P(D)]\,[1 - P(W)] \\ P(M) &= 0.23 \end{aligned} \tag{9}$$

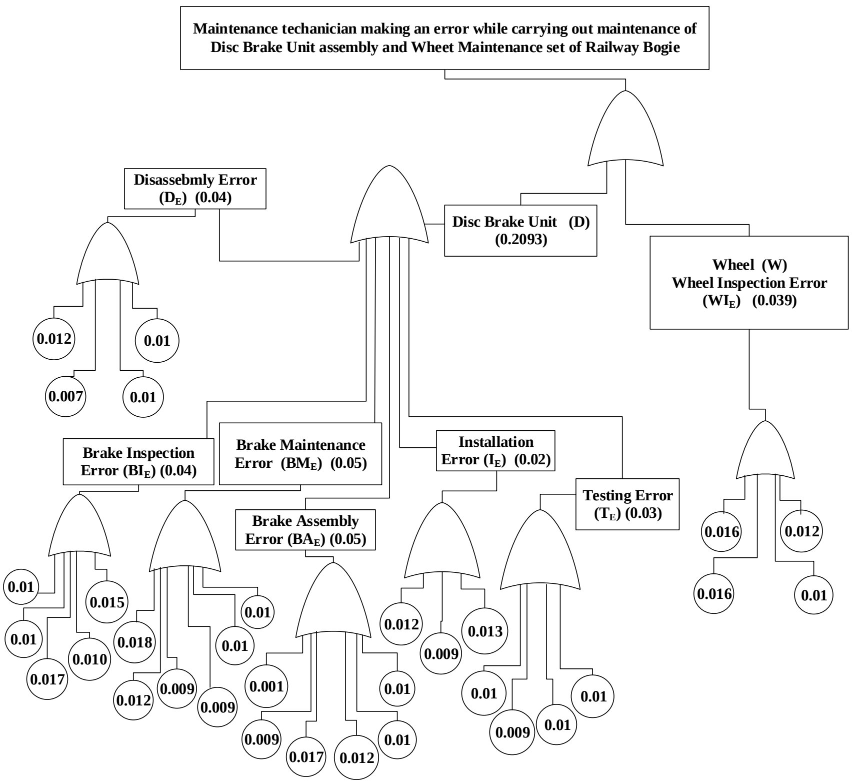

Fig. 4. Fault tree with the calculated value of top event and basic fault events (causes).

Thus, the probability of the technician committing an error was found to be 0.24. The fault tree of the above calculated event occurrence probability values appears in Fig. 4.

4. Conclusions

This paper presents the need for interventions in the human factor elements of maintenance tasks performed on railway bogie. For maximum reliability, equipment must be kept in good working condition, and for this, regular maintenance is critical. A number of factors directly or indirectly result in a decline in human performance, leading to errors in maintenance tasks. This paper presents a straightforward case study of human error probabilities in a railway maintenance system, looking specifically at railway bogie. By looking at a number of error producing conditions and their effect, it finds the probability of human error for the whole bogie to be 0.24. It concludes that error producing conditions such as time pressure, ability to detect and perceive problems, the existence of over-riding information, the need to make absolute decisions, and a mismatch between the operator and the designer's model are major contributors to human error. The case study can help maintenance management understand various error producing conditions and serve as an input to modify policies and develop better guidelines for railway maintenance tasks.

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